

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2006		2. REPORT TYPE		3. DATES COVERED 00-00-2006 to 00-00-2006	
4. TITLE AND SUBTITLE Volumetric Acoustic Intensity Probe				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory, 4555 Overlook Avenue SW, Washington, DC, 20375				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 2	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Volumetric Acoustic Intensity Probe

E.G. Williams
Acoustics Division

Introduction: How often have we sat in an automobile or airplane and wondered where an annoying sound source was coming from? In military vehicles and aircraft, or habitation spaces on ships and submarines, annoying sources promote fatigue and may interfere with mission success. Identification of these sources is crucial so that measures may be taken to quiet them. Pressure or vibration sensors are generally not successful in localization and identification of noise sources. Modern metrology has turned to intensity probes for a solution. These probes have had marked success since they measure the direction and magnitude of energy flow at the measurement point. When used to scan over surfaces or in an array configuration, they are also effective at locating noise sources. The ability to locate detrimental noise sources and quantify them has taken a quantum leap forward with the invention at the Naval Research Laboratory (NRL) of a new and radically different type of intensity probe. Called the Volumetric acoustic Intensity Probe (VIP), it works by imaging the acoustic intensity vector in a volume nearly a cubic meter in size using an array of relatively inexpensive microphones. This holographic-like imaging capability is remarkable since it tracks the energy flow throughout this volume at points in space where measurements are not made. Furthermore, energy-flow tracks of multiple noise sources are separated by state-of-the-art, front-end signal processing.

This new measurement device can be used to diagnose any complex noise source, whether flow-noise or shock induced, for example.

Description and Theory of Operation: The VIP consists of a nearly transparent spherical array of 50 microphones optimally positioned on an imaginary spherical surface of radius 0.2 m. The VIP uses high-level mathematics (spherical wave-function expansions) to convert the measured pressure field into a vector intensity field in a volume that is 0.8 m in diameter centered at the sphere origin. The operational array is shown in Fig. 1 in front of a window inside a Boeing 777 aircraft. The microphone probes can be seen pointing outwards from the center of the sphere along with an interconnecting framework. The VIP is held by a horizontal attachment boom shown below center on the right of the figure. Time-domain pressure at the 50 microphones and optional reference transducers (placed on suspected sources) are recorded simultaneously. Advanced signal processing based on cross-power spectra and high-level mathematics based on nearfield acoustical holography (NAH), both used for the tracking of the intensity vector, are coded in software on a fast PC with output on a LCD display consisting of frequency domain plots of the power flux (vector intensity) in a volume starting at the origin of the array and extending to a radius twice that of the array, as shown in Fig. 2. Currently, the 50-microphone design works in the frequency band of 0 to 1400 Hz in air with an upper limit of 6 kHz in water. The upper frequency limit can be extended by increasing the number of microphones used in the array.

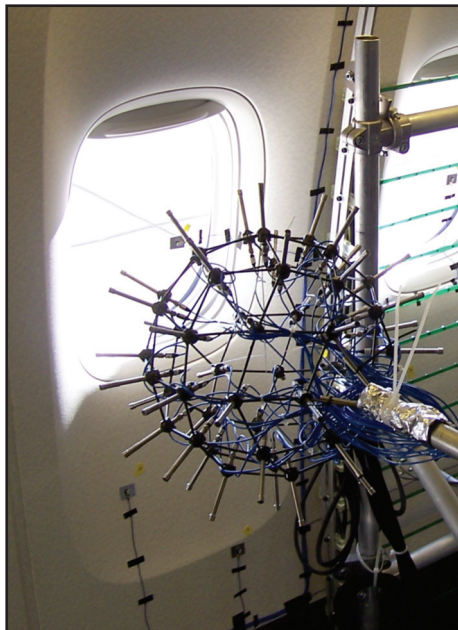


FIGURE 1
Fifty-element spherical array designed and constructed at NRL and mounted on a horizontal beam inside a Boeing 777 aircraft.

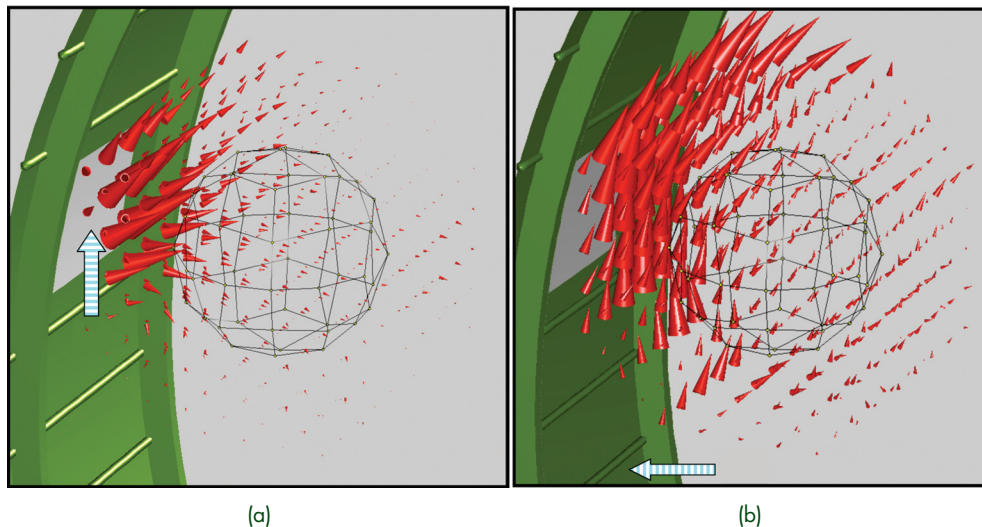


FIGURE 2

Front-end signal processing successfully separates two independent noise sources. Results are at 732 Hz in front of a bare sidewall of a Boeing 757 aircraft flying at standard speed and altitude reconstructed from a single measurement with the VIP. A sketch of the sphere location (wire frame) as well as one vertical segment (colored green, located between two vertical king frames) of the fuselage sidewall is shown. An acoustic source (not shown) driven by a loudspeaker was located at point (a) and the second source was a fuselage horizontal panel (b), which was exterior-driven by flow noise and was resonant at 732 Hz.

Example of Operation: An in-flight experiment in a Boeing 757 aircraft, carried out in cooperation with NASA Langley and The Boeing Company, tested the operation of the VIP in a complex noise-source environment. Time data was recorded digitally for off-line processing and for testing and development of the capabilities of the VIP. The array was placed close to a bare sidewall (trim panels and insulation removed) of the fuselage similar to Fig. 1. Front-end signal processing using about 3 min of recorded data created pressure holograms (amplitude and phase of pressure in each of 270 frequency bins) correlated to individual references out of a suite of reference accelerometers and microphones used in the measurement. Coherence procedures pick the most important holograms for conversion into intensity fields at each frequency or in third-octave bands. In the sample result shown in Fig. 2, the 757 aircraft was flown at typical speed and altitude; the fuselage sidewall was excited by the exterior flow noise, radiating noise into the interior of the aircraft. A second source of noise was a controlled acoustic point source driven with pseudorandom noise by a loudspeaker and placed very close to the center of a window. A resonance of one of the fuselage panels below the window was identified at 732 Hz. Results from the VIP for the frequency bin at 732 Hz are displayed in Fig. 2. Note the front-end signal processing was successful at separating the two noise sources, displaying the most significant one (correlated highly to the acoustic point source) on the left and the second one (correlated highly to the resonant panel) on the

right. The latter intensity field surprisingly follows a tangential path along the fuselage sidewall as it radiates out of the panel at the bottom of the picture. The VIP is very successful at resolving and tracking the energy-flux fields of these two uncorrelated noise sources.

Summary: Although this device has quickly caught the attention of the commercial aircraft industry, it is an ideal tool for the Navy and provides the ability to locate sources of sound in confined interior spaces like the cabins of military vehicles, surface ships, submarines, and aircraft; as well as in exterior spaces such as near a ship hull. The VIP tracking algorithm is very fast so that the probe can be used in real time, with LCD displays on a local laptop locating noise sources as the probe is physically moved, scanning for noise sources in a field application. The underlying technology is not limited to acoustic applications, but with a change from pressure sensors to electromagnetic field sensors, one would be able to image the Poynting (electromagnetic intensity) vector in the volume in the same way.

Acknowledgments: The experimental work was carried out under the direction (and funding) of Richard Silcox of NASA Langley in cooperation with Bernard Sklanka of The Boeing Company. Theoretical development and probe design and construction were supported by ONR.

[Sponsored by ONR]

